Decline of eucalypt trees in tablelands of New South Wales, Australia

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Abstract: *Eucalyptus* species are the native and major plant group in Australian landscapes. Since European settlement, eucalypt trees heavily decline in the tablelands of New South Wales. Tree recruitment bog down and the landscape ecosystem hardly recovers to the original state. This paper introduces the history of eucalypt trees and native shrubs decline, analyzes reasons of seedling recruitment decrease in this region, such as clearing, grazing, fire, competition from exotic species, dieback, insects, drought and so on, and summarizes the probable conditions of eucalypt tree recruitment, such as suitable conditions of seedling survival, sufficient seed supply, keep from predation, suitable germination conditions, non-grazed environment, mechanical treatment, weed control, fire regime, disease control etc, lending suggests how to preserve and encourage eucalypt trees recruitment in the area .

Keywords: Eucalypt; Decline; Recruitment

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Introduction

Woody plants are important components of landscapes in Australia, of these, most natural tree species was *eucalyptus* spp., which provide key services to landscape function and other components of ecosystems. Eucalypt trees in particular, have high structural, functional and aesthetic significance in Australia, such as controlling soil erosion and salinization, and also have commercial uses in timber, firewood, fodder and honey production, as well as provide critical habitats for many wildlife species. However, in the past over 150 years, density of eucalypt trees has a drastic decline in some parts of landscapes in Australia resulting in variegated and often dysfunctional landscapes.

The decline, land degradation, soil erosion and salinity have been found throughout the agricultural lands of Australia (Curtis and Reeve 1988). Of the total land area of Australia used for agricultural and pastoral production, 50% needs rehabilitative treatment or change in management practices, to prevent further degradation (Cremer 1990; Semple 1997a). In the wheat belts of southeastern and southwestern Australia, woodlands with eucalypt dominance have been completely eliminated from most landscapes with as much as 95% of the native vegetation removed in some zones (Yates and Hobbs 2000). The land data from CSIRO Water and Land Resources (Cremer 1990) showed that at least 88 million hectares, or 36% of the original woodlands of Australia, have been cleared or largely cleared. The highest proportion was 69% in Victoria, and 50% in NSW (New South Wales) (Cremer 1990). After ten years, Yates and Hobbs (2000) reported that in some areas of NSW, more than 90% of all native vegetation had been cleared. In NSW alone, 43 plant, 12 bird, and 26 mammal species are now extinct; another 191 plant and 38 animal species are endangered if current threats continue (www.npws.nsw.gov.au/ wildlife/savebsh2.htm). The reduction in floral diversity of remnants, especially *eucalyptus* spp., strongly influences the diversity of fauna (Windsor 2000b; Schabel and Eldridge 2001).

Since European settlement, the change of land use has resulted in a variegated vegetation and land degradation. NSW, as the centre of economy, culture, politics and tourism of Australia, with a population of over one third of Australia, has a vegetation cover that does not sustain agricultural industries. Landscapes and ecosystems are damaged and eucalypt tree and native shrub recruitment become unbalanced. Economic and social problems will increase if remnant landscapes continue lose function.

History of trees and shrubs decline in New South Wales

Since Europeans and state governments viewed woodlands as ideal for agriculture in the high rainfall zone (above 750 mm annual rainfall), these woodlands were rapidly converted into farmland for grazing and cropping businesses (Yates and Hobbs 2000). In many regions, lands degraded and salinity, acidification, waterlogging, soil erosion and soil structure decline have extensively occurred (Windsor 2000a, b). The remnant woodlands are located mainly on rocky areas, upper slopes, poorer soils and alluvial flood plains that are subject to periodic inundation (Yates and Hobbs 2000). The remnants are often limited in size and distribution to patches along railway lines, roads, cemeteries and areas unsuitable for agriculture (Windsor 2000a, b).

Why eucalypt tree and native shrub declined over large areas, several primary reasons should be discussed.

Clearing

"In the 1840s development of the region was marked with blazed trees, no fences, with sheep grazed on the uncleared…by the 1870s many people were writing with alarm at the arising shortage of wood, timber, shade and shelter for stock as well as the worsening severity of frost and the effect of the landscape" (Curtis 1989). When eucalypt trees were cleared, the understorey shrubs were taken with them. Clearing not only changes woodland structure and function, encourages pioneer herbs to increase, but also encourages soil erosion (Cremer 1990). The habitat for native fauna is removed (Curtis 1989) and bird populations and insects can build up to plague proportions that often kill remain-

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ing trees (Allen 1983), which have been a vicious circle. Therefore, clearing the original vegetation which eucalypt trees and native shrubs once dominated is the root factor that caused a series of environmental problems in Australia.

Grazing

The introduction of domestic livestock greatly increased grazing pressure. Plant community structure and composition are changed by grazing of livestock (cattle, sheep and goats, etc.), rabbits, and native fauna (kangaroos, etc.) (Clarke 2000). Before European settlement, the warm season perennial grasses (such as *Themeda triandra, Aristida ramose, Cymbopogon refractus*), and the yearlong green perennial grass (*Poa sieberana*), generally dominated the herbaceous layer (Curtis 1989), but these native grasses were largely eliminated by overgrazing in the past over 150 years (Semple 1997a). Short warm season native grasses (*Bothriochloa macra, Sporobolus elongatus, Eragrostis* spp and *Chloris truncata*), yearlong green perennial grasses (*Austradanthonia* spp., *Dichelachne* spp.), and naturalized cool season annual plants (*Vulpia* spp., *Aira cupaniana, Briza minor*) replaced these pre-settlement grasses (Curtis 1989; Windsor 2000b).

The action of the hard-footed domestic animals increases soil disturbance, such as compaction and erosion and arid and also influences the spread of weeds whose seeds are carried in animals' wool and fur (Windsor 2000a, b). Eucalypt trees and native shrubs also were affected by grazing, such as killing juveniles, reducing the flowering and fruiting (Curtis 1989). However, in some areas the problem is not tree and shrub decline, grazing sheep eat the seedlings of palatable species rather than inedible species (Allen 1983). With the removal of the palatable specie competition, inedible species allowed to grow much better (Hodgkinson 1979).

As livestock population grows up, native animals such as rabbits and kangaroos, for example, increasing rapidly due to lack of hunt by Aboriginal, turn to be disaster and stress on native grass.

Grazing management is a key factor to disturb area of the understorey vegetation and will shift the dominant species from native warm season perennial grasses to cool season annual grasses or exotic grasses. Animal's actions of defoliation and trampling change not only the vegetation but soil nutrient cycle. Therefore, in the presence of persistent grazing, tree and shrub recruitments are strongly affected. However, grazing is part of Australia's economic and cultural bases, and exclusion of grazing over vast areas is not realistic. Therefore grazing must continue with restoring ecosystem processes. As we know that no grazing is better for tree and shrub recruitments but the threshold beyond which recruitment is severely affected is unknown.

Fire

Fire changes the structure and functioning of plant community especially nutrient recycling processes (Williams 1994; Noble 1996). Many Australian plants are adapted to surviving after fire and rely on this extreme disturbance for successful germination and recruitment (Walker and Singh 1981). Before European settlement, Aboriginals burnt vegetation for a variety of reasons including the encouragement of fresh grasses growth to draw kangaroos to graze for easier hunt (Curtis 1989). Many native plants, including eucalypt trees, have special mechanisms for re-establishing after fire. Aboriginals were responsible for converting large areas of eucalypt forests into grassland plains and savannah woodlands that were subsequently maintained as disclimax communities by regular firing (Allen 1983).

Eucalypts sprout from epicormic shoots lying dormant under the bark of stem (Allen 1983). Fire is also of benefit for seeds, for example, *Acacia, Callitris* spp. and *Banksia*, hard woody fruits that open after heat (Curtis 1989; Windsor 2000a). *Eucalyptus* and *Acacia* species are adapted to survive in landscapes and environment with pre-settlement natural disturbance factors. Since European settlers turned the woodlands to grazing and cropping lands, and changed the fire regime, fire does not occur frequently as before. Fire is a very important factor for eucalypt species recruitment in wide lack of burnt areas.

Competition from exotic species

Exotic pasture species generally require relatively high soil moisture and fertilizer application to maintain populations and native species do not overcome long-term ecosystem degradation (Windsor 2000a). Native shrubs and grasses are absent because they cannot compete in the continuous sward of exotic perennial grasses, and often only occupy some low fertility areas (Semple 1997b). In southeast wheat belt of Australia, the native grasses *Themeda* spp., *Stipa* spp. largely replaced by *Austradanthonia* sp., *Trifolium* spp., *Lolium perenne, Bromus* spp. and *Vulpia* spp., etc. (Semple 1997; Zhang 2003).

Native eucalypt species often give way to the exotic species. Studies show that eucalypt trees and native shrubs usually company with native grasses, but when the understorey changes, the woody overstorey tend to change either; seedlings of these species find it difficult to survive at the affected environment.

Dieback

Dieback is premature, relatively rapid decline and death of native eucalypt trees, and is a widespread problem of varying intensity in the wheat-sheep and high rainfall zones of eastern and south-western Australia (Reid and Landsberg 2000). In pastoral regions it is becoming increasingly common throughout Australia, and is often associated with heavy defoliation by insects (Curtis 1989; Landsberg 1990). The cause of the dieback was attributed to environmental changes following the clearing and livestock grazing that accompanied European settlement (Reid and Landsberg 2000). Dieback refers to a symptom of bad health of tree caused by a large number of factors, particularly in agricultural areas where the natural environment has been extensively modified (Reid and Landsberg 2000). Dieback-affected eucalypts typically have poor crowns with sparse foliage and a large proportion of dead twigs and branches (Curtis 1989), and root systems are similarly reduced (Reid and Landsberg 2000).

The dieback causes of eucalypt trees may vary within geographic regions. Insects, salinization, pathogens, senescence, drought, and so on, have all been implicated (Curtis 1989; Reid and Landsberg 2000). Compared with healthy eucalypt trees, insects more heavily graze the foliage of dieback eucalypt trees, because the quality of their leaves is generally superior (Landsberg 1990). Similarly, the extent of dieback is thought to be related to topography, being most severe on flatter, poorly drained sites regardless of soil type (Schabel and Eldridge 2001).

From these studies, it can be concluded that dieback occurs after natural environment was changed over large areas. Any disturbance factors associated with clearing and grazing as well as other factors might result in dieback among eucalypt species. Dieback affects the quantity of flowers and seed production and these in turn affect the recruitment of eucalypt trees.

Insects

Ants are by far the most important post-dispersal seed predators in Australia and influence plant population dynamics (Andersen and Ashton 1985; Curtis 1989). One eucalypt tree can produce average one kilogram of seed per year, more in a good year, and the number of seeds per kilogram ranges from 3 300 to 2 300 000 depending on different species, but post-dispersal seed predation by ants to be 60%–100% for *Eucalyptus* spp. (Venning 1988). Yates (1996) observed that a large proportion of eucalypt seeds were eaten by ants, and also had short-term viability in the soil. The natural balance has been upset by human activity so that one or more insect species will develop into plague numbers, which cause severe defoliation and subsequent tree decline (Allen 1983). In the tablelands of eastern Australia, dieback and mortality of eucalypt trees are linked with high levels of defoliation by insects (Clarke 2000). Wingless grasshoppers can also kill *Eucalyptus* seedlings and other woody species when they move from "improved" pastures into adjacent remnant vegetation (Clarke 2000). Insects tend to eat a greater area of thin, low specific weight leaves than thicker leaves (Landsberg 1990).

Insects cause eucalypt tree decline in two ways. One is reducing viable seeds by predation, and the second way is damaging foliage so that photosynthetic capacity significantly reduced. Eucalypt seed level in soil is the basic factor for recruitment, and with ant predation the amount of seed shed from trees can be critical. If eucalypt tree health deteriorates, recruitment around them will be curtailed. Insect control should be run in protecting eucalypt population in a long term, and stretch forest is not prone to suffer insect disturbance from literature review.

Drought

Overgrazing, habitat destruction and clearing along watercourses and inappropriate places, combined with severe droughts, have resulted in local loss of woody species, especially eucalypt species (Windsor 2000a). Lack of soil water is commonly reported to be the cause of seedling death across a range of woodland species especially in the sub-humid and semi-arid regions (Hodgkinson 1979). Even when there is little influence by people, drought usually is the enemy of successful eucalypt tree recruitment in the Tablelands of NSW because of rainfall shortage. The hard fruits of many eucalypts seasonally open in drought or post-fire and release seeds but without suitable rainfall, germination and establishment will not follow (Windsor 2000a).

These seven factors are major causes for the decline and poor recruitment of eucalypt tree, but sometimes frost, flood, topography and so on contribute as well. Mature and/or senescent eucalypt trees can often be seen without nearby recruitment. In the absence of recruitment these eucalypt trees will not be replaced and eventually they will disappear from these areas.

How to attract eucalypt tree to settle down

Eucalypt species have been dominant in Australian tablelands though the recruitments are rare. Eucalypt trees could be attractive in the region by the following methods.

Conditions of seedling survival

There are four stages in the life cycle of plants: seeds, seedlings, juveniles and reproductive adults. Williams (1971) stated "In principle, the maintenance of a plant in a community depends upon the longevity of the plants, the opportunity during that life-span to produce viable seed, the viability of the seed in the soil, and the opportunity to germinate and establish". Usually the number of individuals surviving from one demographic stage to the next is very low because of "environment sieves". These factors include resource availability (nutrients, water etc.), abiotic limiting factors (salinity, pH etc.) and biotic factors (competition, herbivores and pathogens) (Venning 1988). Successful recruitment of eucalypts depends on the chance occurrence of heavy seed fall, high soil moisture and suitable temperature for germination, as well as a favourable weed free seedbed (Venning 1988). Curtis (1989) estimated that these conditions occurred only once every 10–20 years in the Northern Tablelands of NSW. In higher rainfall country of South Australia, natural regeneration is associated with low feral animal populations, low grazing pressure by domestic stock, the presence of scattered trees, lack of "pasture improvement", and above average rainfall for two consecutive years (Lawrence 1998; Windsor 2000a).

Reducing herbage competition by cultivation and applying herbicides prior to expected seed fall, and controlling grazing following emergence, have been suggested as ways of enhancing regeneration (Venning 1988; Lawrence 1998). In the western Australian wheat belt, eucalypt seedling recruitment in *E. salmonophloia* woodlands, for example, was observed following a number of different large-scale disturbances including fires, tornadoes, droughts and floods (Yates 1996). In adjacent undisturbed woodland, eucalypt seedling recruitment was not observed (Yates 1996). Therefore, recruitment conditions are complex and vary spatially. Even in the same area in different periods, or different topography, the disturbance factors appear to be different.

Research suggests that for eucalypt successful recruitment the following requirements need to be met.

Sufficient seed supply

Recruitment is often reduced by insufficient seed supply and lack of predator satiation (Curtis 1989; Lawrence 1998). The most long-lived components of woodlands are the eucalypt trees. Here, seed is held in eucalypt capsules in the canopy and some are stored briefly in the soil, and these seeds on the surface are prone to the herbivory and fire scorch (Venning 1988). Seeds are released following dry warm weather, and fire also stimulates seed fall (Venning 1988). Accumulation of seed banks on plants or in soil is affected by seed supply, seed losses (from predation) and the longevity of the remaining seed (Curtis 1989; Semple 1997a). If native shrubs and eucalypt trees with canopy seed banks release seeds after a disturbance (fire, wind throw, drought) that kills part of or the whole plant occur, much of the potential for seed bank accumulation is lost even before seeds are dispersed (Venning 1988). Furthermore, attribution of the dispersed seed bank by predators, pathogens or physical factors reduces seed available for germination if the time between seed release and germination cues (rainfall) is lengthy. Most eucalypts produce seeds each year. Many forestry species such as *E. camaldulensis* produce relatively large quantities of seed every two or three years, others such as *E. gomphocephala* and.*E. maculata* produce large crops over longer intervals (Florence 1996). Because seed production is influenced by many factors such as profusion of flowers, climatic conditions, efficiency of pollination, insect and bird damage, age and health of the tree as well as stand density therefore years of high seed yield cannot be readily predicted (Venning 1988; Florence 1996). The highest density of seedlings at Mansfield occurred near the edge of the canopy (Curtis 1989). As most of the seed falls in this region, these observations suggest that some eucalypt seed remains after

seed-harvesting ants are satiated. If this were the case, then emergence would be almost wholly a function of the co-occurrence of suitable rainfall (Lawrence 1998).

Because plant growth has its own rhythm, large crops of seeds are sometimes produced. Plant population survival is dependent not only on the quantity of seed produced but the quality of that seed. Those seeds escaping predation and pass "environment sieves" are available for germination under suitable rainfall. Enough viable seed supply is the basic factor for recruitment, because even when suitable conditions prevail, the recruitment will not occur without viable seed supply.

Surviving predation

Ants often eat most of the fallen seed (Venning 1988; Curtis 1989). But when ants were excluded in remnant woodland and a soil seed-bank was created artificially, seeds germinated but no seedlings survived because other suitable conditions didn't occur (Yates 1996). The study suggests that the destruction of seeds by ants during inter-disturbance periods has little effect on eucalypt recruitment for their seedlings unlikely to establish (Yates 1996).

However, disturbance as a result of human activities and farming practices has probably enhanced the predation of eucalypt seed by ants. This requirement for lower predation is poorly understood but is likely to be influential.

Suitable germination conditions

Drought followed by good rainfall appears to result in mass eucalypt recruitment (Windsor 2000a). Many areas where there is regeneration have the same age group of recruits or a series of distinct ages that demonstrates eucalypt recruitment occur in suitable years but not every year (Semple 1997a; Windsor 2000a). Successful seedling establishment has also been associated with above average rainfall (Curtis 1989). Good regenerators often occur on the lee side of eucalypt tree clumps and south of the parents (Semple 1997a), and the amount of soil moisture was significantly associated with position around eucalypt trees (Lawrence 1998). In general, compared to paddocks, roadsides were characterized by a greater cover of trees, shrubs, and surface debris, greater diversity of trees and shrubs, greater recruitment of trees, healthier trees and ground storey plants, and a less modified environment, which will benefit recruitment (Schabel and Eldridge 2001). Conditions suitable for germination occur at the beginning of the winter wet season in south-western Australia when soil temperature is still suitable and soil moisture and atmospheric humidity are frequently high (Yates 1996). Temperature and soil moisture are major factors affecting eucalypt seed germination (Curtis 1989; Semple 1997a). Seeds of many plant species have evolved to maximize the likelihood of germination occurring when conditions are most suitable for seedling establishment (Yates 1996). That high atmospheric humidity will overcome the effects of lower soil-water potentials (Yates 1996).

Eucalypt seeds have a wide range of temperature suitable for germination but differ in germination rates at extreme temperatures. Thus, soil temperature, rainfall and the soil water are crucial for recruitment. Given that above-average rainfall for several months is needed, the water-holding capacity in different soil types, the topography and presence of mature trees will all affect soil conditions at the microenvironment level. Eucalypt tree recruitment occurs in a discontinuous manner in space and time.

Non-grazed environment

Seedlings of *Daviesia mimosoides* on the burnt areas 5 years earlier and then grazed had an average height of 11 cm compared with 30 cm on burnt areas that without grazed (Leigh and Holgate 1979). The seedling density had also declined to a level approaching that of unburnt plots (Leigh and Holgate 1979). After 5 years, seedling density was much higher on the burnt and ungrazed plots (Leigh and Holgate 1979). Three to four times as many seedlings established on the ungrazed plots relative to those that were grazed (Leigh and Holgate 1979). Overgrazing removes pasture growth as well as the edible species, and remaining inedible species usually become dominant and there is increasing erosion (Curtis 1989; Windsor 2000a). "Woody weeds" thrive after the removal of their competitors for moisture and nutrients (Leigh and Holgate 1979; Windsor 2000a).

Grazing includes eating and trampling as well as any other activities of herbivores. Leaves of eucalypt seedling and native shrub are easily selected for eating and stems are readily damaged. By comparing paddocks and roadsides, or comparing paddocks with different managements, the effect of grazing on recruitment can be assessed.

Mechanical treatment

Significant increases in germination and establishment of *E.* spp. occurred when accumulated litter is removed (Leigh and Holgate 1979). Eucalypt regeneration commonly occurs on recently disturbed sites lacking vegetation cover (Leigh and Holgate 1979; Semple and Koen 1997). Eucalypt seedlings usually are found beyond the area beneath the canopy (Semple 1997a; Windsor 2000a). Curtis (1989) indicated that seedbed conditions are critical for eucalypt seedling recruitment. They found that recruitment only occurred where the grass sward was thin and the soil was bare (Curtis 1989). Therefore, if the last four factors exist and seeds fall at the bare soil, then germination is possible.

Weed control

Mechanical grading of the uppermost topsoil to a depth of 2-5 cm (to remove the weed seed bank) or spraying herbicides, or physical removal of weeds will increase survival of eucalypt recruits (Venning 1988; Semple and Koen 1997). In another study, survival was best when competition from herbaceous species was minimal (Curtis 1989).

Weed control will also decrease competition for eucalypt seedlings and juveniles. Weeds will also grow up again; therefore, weed control should occur at a time before suitable conditions for seed germination and establishment.

Fire regime

Fire consumes the above ground parts of shrubs and grasses and stimulates the opening of the hard fruits thereby releasing seeds into soil. Many Australian native plants have adapted to living with fire (Walker and Singh 1981; Windsor 2000a). Burning can help the organic matter release nitrogen, phosphorus and sulfur into soil (Windsor 2000a) providing more valuable nutrients for eucalypt tree and native shrub recruits. .

Disease control

Healthy trees and communities always have good seed supply and regeneration occurring (Schabel and Eldridge 2001). Disease control for trees and communities will benefit recruitment.

The floristic composition of woodlands is influenced by climate, soil type, topography, hydrology, biotic interactions such as grazing, and large-scale disturbances such as fire, tornadoes, floods and droughts (Yates and Hobbs 2000). These germination

characteristics minimize the chance of eucalypt seeds germinating at times when the probability of seedling establishment is low (Yates 1996). Restoring an ecosystem structure and function as close as possible to the original vegetation, is a more achievable goal (Windsor 2000a).

Australian ecosystems in the agricultural zone were highly disturbed over the past 150 years, and now recruitments of eucalypt trees and native species are urgent requirement. Even necessary conditions for recruitment occur, but that recruitment is still rare in some zone, is not well understood. Further project will focus on recruitment of trees and shrubs, especially *Eucalyptus* and *Acacia* species in remnant woodlands and agricultural zones, and provide some suggestions for natural landscape rehabilitation and for threatened remnants.

References

Anderson, R.H. 1956. The Trees of New South Wales [M]. Sydney: A. H. Pettifer, Government Printer.

Allen, R.J. 1983. Tree decline in western New South Wales: fact or fiction [J]? Australian Forestry, **46**(4): 303-310.

Charman, P.E.V. and Murphy, B.W. 1991. Soils-their properties and management [C]. In: A Soil Conservation Handbook for New South Wales. Sydney: Sydney University Press.

Clarke, P.J. 2000. Plant population processes in temperate woodlands of eastern Australia—premises for management. Temperate eucalypt woodlands in Australia, biology, conservation, management and restoration [C]. New South Wales: Surrey Beatty & Sons. Pp. 298–317.

Cremer, K.W. 1990. Trees for rural Australia. CSIRO division of forestry and forest products [M]. Canberra: Inkata Press.

Curtis, D. and Reeve, I. 1988. Growback in Victoria—Community responses to tree decline [M]. Armidale: Armidale tree group Publ..

Curtis, D. 1989. Eucalypt re-establishment on the northern tablelands of New South Wales [D]. New South Wales: A thesis submitted for the degree of Master of Science of the University of New England. Armidale.

Florence, R.G. 1996. Ecology and silviculture of Eucalypt forests [M]. CSIRO Publishing House.

Hodgkinson, K.C. 1979. The shrubs of poplar box (*Eucalyptus populnea*) lands and their biology [J]. Australian Rangeland Journal, **1**: 280–293.

Landsberg,J. 1990. Dieback of rural eucalypts: does insect herbivore relate to dietary quality of tree foliage [J]? Australia Journal of ecology, **15**: 73–87.

Lawrence, J., Semple, W.S. and Koen, T.B. 1998. Experimental attempts at encouraging eucalypt regeneration in non-native pastures of Northern Victoria and Central Western NSW [C]. In: Eucalypt regeneration in pastures. Proc. Linn. Soc. New South Wales.

Leigh, J.H. and Holgate, M.D. 1979. The responses of the understorey of forests and woodlands of the south tablelands to grazing and burning [J]. Australian Journal of Ecology, **4**: 25–45.

Noble, J.C., Tongway, D.J., Rober, M.M. and Whitford, W.G. 1996. Fire studies in mallee (*Eucalyptus* spp.) communities of Western New South Wales: spatial and temporal fluxes in soil chemistry and soil biology following prescribed fire [J]. Pacific Conservation Biology, **2**: 398–413.

Reid, N. and Landsberg, J. 2000. Tree decline in agricultural landscapes: What we stand to lose [C]. Temperate eucalypt woodlands in Australia, biology, conservation, management and restoration. New South Wales: Surrey Beatty & Sons. Pp. 298–317.

Schabel, J. and Eldridge, D.J. 2001. A comparison of roadside and paddock vegetation in the box woodlands of Eastern Australia [R]. Occasional Paper No.7 school of Geography, The University of New South Wales. A technical report prepared for the central west catchment management board, New South Wales.

Semple, W.S. 1997. Eucalypt regeneration in white box (*Eucalyptus Albens* Benth.) communities [D]. A thesis submitted in partial fulfillment of the requirements for the degree of master of letters (plant biology) at the University of New England, Armidale, NSW.

Semple, W.S. 1997. Native and naturalized shrubs of the bathurst granites: past and present [J]. Gunninghamia, **5**(1): 4, 9–80.

Semple, W.S. and Koen, T.B. 1997. Effect of seedbed on emergence and establishment from surface sown and direct drilled seed of *Eucalyptus* spp. and *Dodonare Viscosa* [J]. Rangeland Journal, **19**(1): 80–94.

Venning, J. 1988. Growing trees for farms, parks and roadsides: a revegetation manual [M]. Melbourne: Lothian Publishing Company Pty Ltd..

Walker, D. and Singh, G. 1981. Vegetation history [C]. In: Australian vegetation, Greves, R.H. Eds. Cambridge: Cambridge University Press, p26–44.

Williams, R.J. and Ashton, D.H. 1987. Effects of disturbance and grazing by cattle on the dynamics of healthland and grassland communities on the Bogoing High Plains, Victoria [J]. Australian Journal Botany, **35**: 413–431.

Williams, J.E., Whelan, R.J. and Gill, A.M. 1994. Fire and environmental heterogeneity in southern temperate forest ecosystems: implications for management [J]. Australian Journal of Botany, **42**: 125–137.

Windsor, D.M. 2000. A review of factors affecting regeneration of box woodlands in the central tablelands of New South Wales. Temperate Eucalypt woodlands in Australia, Biology, Conservation, Management and Restoration [C]. New South Wales: Surrey Beatty & Sons. Pp.271–285.

Windsor, D.M., Clements, A., Nolan, M.B. and Sandercock, H. 2000. Recreating eucalypt woodland with a grassy understorey on a gold mine in the central tablelands of New South Wales [C]. In: Temperate Eucalypt Woodlands in Australia, Biology, Conservation, Management and Restoration. New South Wales: Surrey Beatty & Sons. Pp. 298–317.

Yates, C.J., Hobbs, R.J. and Bell, R.W. 1996. Factors limiting the recruitment of *Eucalyptus salmonophloia* in remnant woodlands. III. Conditions necessary for seed germination [J]. Australian Journal Botany, **44**: 283–296.

Yates, C.J. and Hobbs, R.J. 2000. Temperate eucalypt woodlands in Australia an overview. Temperate Eucalypt woodlands in Australia; Biology, Conservation, Management and Restoration [C]. New South Wales: Surrey Beatty & Sons. Pp. 1–5.